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ABSTRACT

This eighth in a series of eight modules for a course titled Mechanical Inspection describes mechanical inspections and electrical tests which are typically performed on installation of rotating equipment. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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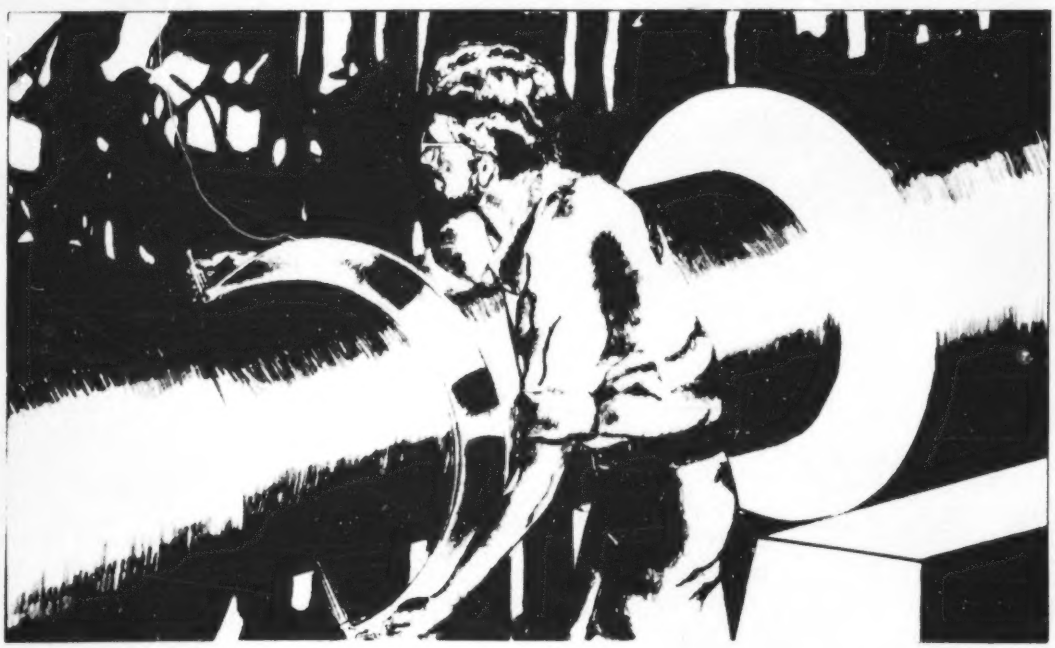
NUCLEAR TECHNOLOGY

COURSE 30 MECHANICAL INSPECTION

MODULE 30-8 Rotating Equipment Inspection



CE 024 284

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 30 MECHANICAL INSPECTION

Module 30-1 Pump Inspection
Module 30-2 Pump Functional Testing
Module 30-3 Valve Inspection
Module 30-4 Piping Inspection
Module 30-5 Surface Cleaning Inspection
Module 30-6 Protective Coating Inspection
Module 30-7 Pressure Vessel Inspection
Module 30-8 Rotating Equipment Inspection

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This module was prepared for General Physics Corporation by Bruce Kinne and John Espy, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

The Nuclear QA/QC Technician performs verification inspections associated with installation and test of rotating equipment. These inspections involve review of documentation, monitoring installation activities, and inspecting critical features. Some inspections and tests of rotating equipment require highly specialized skills. These inspections and tests require the use of personnel with specialization in electrical work.

Rotating equipment in nuclear power plants use electrical motors, diesel engines, or steam turbines as prime movers. Loads for these prime movers include valves, pumps, fans, blowers, AC generators, and DC generators. Any of these loads may be very small or quite large. Largest of all are the main power generators which use the steam from the reactor to generate electrical power.

This module describes mechanical inspections and electrical tests which are typically performed at installation of rotating equipment. Many of these inspections and tests are periodically repeated at intervals of plant operation to verify the continued operability of rotating equipment or to indicate the need for corrective maintenance.

MODULE PREREQUISITES

There are no prerequisites for this module.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. State the purpose of preinstallation and installation inspections.
2. Briefly describe typical preinstallation and installation inspections for rotating equipment.
3. State two reasons why shaft alignment is important and briefly describe two methods of inspecting shaft alignment.
4. Briefly describe the Langmuir theory of lubrication.
5. Briefly describe the operation of given lubrication systems including attached forced feed, external forced feed, gravity feed, self-oiling, grease cup and grease fitting.
6. Define the following terms with respect to lubricating oils:
   a. viscosity
   b. flash point
   c. fire point
   d. auto-ignition point
7. State the purpose of turnover tests of oil lubrication systems by the installation contractor and name four examples of items checked by these tests.
8. Name three examples of items checked with respect to oil lubrication systems during equipment load tests.
9. State the purpose and briefly describe the performance of:
   a. continuity tests
   b. insulation
   c. resistance tests
   d. high potential dielectric tests
   e. starting and run current tests,
   f. vibration tests
   g. generator loading tests

h. automatic features actuation tests.

10. Name three components of current which are encountered during insulation resistance tests and describe the effect of each component on measured insulation resistance.

11. Describe the effects on insulation resistance by surface condition, moisture, temperature, magnitude of test potential, duration of application of test potential, and residual charge.

MECHANICAL INSPECTIONS AT INSTALLATION

Basic Types of Installation

Rotating equipment are received at the power plant site as an integral assembly of prime mover and load or as separate components of prime mover and loads. An example of an integral assembly is the 15KW motor-generator set illustrated in Figure 30-8-1. This equipment is supplied as a "package set" with the motor, generator, and flywheel mounted to a base plate by the manufacturer. Shaft coupling, alignment, and balancing have been performed by the manufacturer.

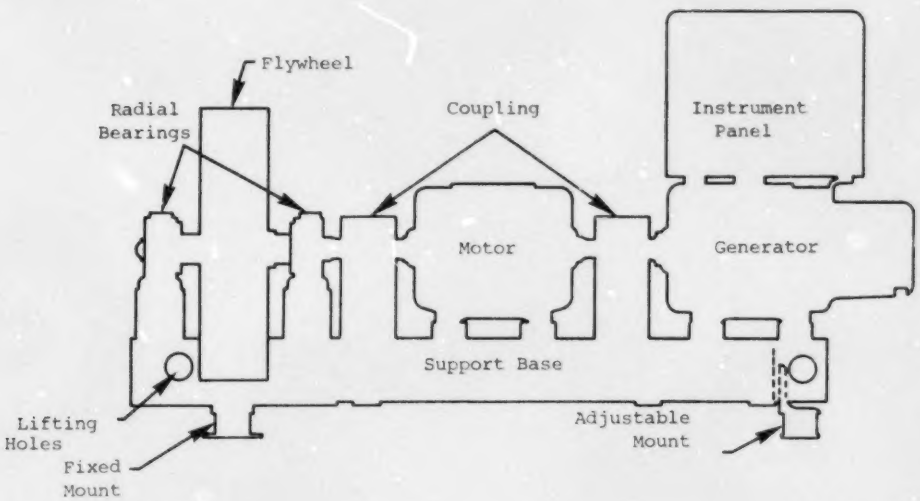


Figure 30-8-1. Integral 15KW Motor-Generator Assembly

Many prime movers are received at the power plant site separate from their loads. For each of these, the manufacturer has balanced the rotor and completely assembled the unit. At the installation site, the unit is mounted to its foundational supports and coupled to its load.

Preinstallation Inspections

As construction of a nuclear power plant procedes, components are frequently arriving. These components are receipt inspected and, unless promptly needed for installation, are placed into storage at the site. As construction activities require components for installation, components are withdrawn from stores and moved to the installation area. Preinstallation inspections verify readiness for installation in terms of materials, procedures and drawings. These inspections consist primarily of visual inspections which verify (1) identification, (2) availability of processes and procedures, (3) physical condition of the component and (4) physical condition of the installation site.

Identification of rotating equipment is provided by its nameplate and receipt inspection acceptance tags attached to the equipment. Nameplate data for electrical motors are illustrative; those data include:

- manufacturer
- type of motor
- horsepower output
- speed in revolutions per minute at rated horsepower
- number of phases
- rated operating frequency in hertz
- rated operating voltage in volts or kilovolts
- current at rated voltage and rated horsepower in amperes
- temperature rise above 40^{o}C at rated load in ^{o}C
- classification number
- manufacturer's style or model number
- manufacturer's serial number.

Nameplates for other equipment provide similar data which characterizes the equipment. Identification inspection compares nameplate data with the requirements of the installation procedures and drawings to verify that the

correct component is selected for installation. Such inspections give particular attention to the type, style, power rating, classification, and speed in order to verify use of the correct component.

Installation activities are performed in accordance with written instructions which are collectively termed job package. The job package contains or references necessary procedures, drawings, instructions, check lists, equipment and fixtures for each segment of installation. The preinstallation inspection of processes and procedures verifies the availability of a complete job package and compliance with prerequisites specified by the job package. For installation of rotating equipment, this portion of preinstallation inspection typically verifies the following:

- approved procedures and installation drawings are available
- installation preparations are complete such as removal of packaging, cleaning, conditioning, and preliminary positioning
- necessary jigs, fixtures, and handling equipment are available

Preinstallation inspection of the physical condition of rotating equipment verifies that the quality of the equipment has been maintained through the operations which relocated the equipment to the specific installation area. Equipment is visually examined for damage, cleanliness, lubrication, and completeness of accessory hardware. In addition, this inspection verifies that any previously reported nonconformance has been corrected.

Preinstallation inspection of the site condition visually examines the specific installation area. This examination verifies cleanliness of the immediate area, protection from possible adverse effects from adjacent construction activities, protection from inclement weather,

and installation of specified supports and mounts.

Installation Inspections

Installation inspections verify completion of installation work in compliance with the procedures and drawings which comprize the job package. These inspections are primarily comprized of leveling, alignment, completeness of installation and freedom of rotation.

Requirements for leveling are specified by the installation drawing and associated installation procedure. As size of rotating equipment increases, the accuracy of leveling typically becomes more demanding. Dependent on accuracy requirements. leveling of rotating equipment is inspected by precision level, optical telescope, or laser beam.

Alignment of rotor shafts from the prime mover to the load is necessary to prevent vibration and bearing overloads. Where alignment requirements have a tolerance of several thousandths of an inch, straight edges and feeler gages are used for alignment inspection as illustrated in Figure 30-8-2. With the straight edge placed against one hub, the gap between the straight edge and the other hub indicates the extent of misalignment.

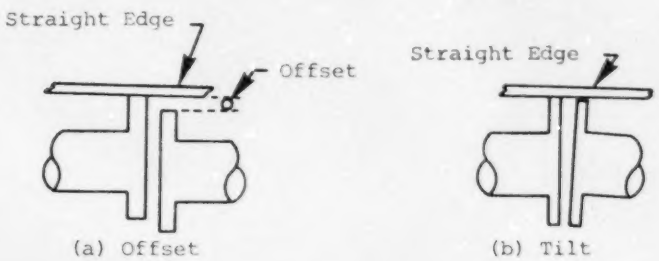


Figure 30-8-2. Alignment Inspection With Straight Edge

A more precise inspection of alignment is possible with dial indicators as illustrated in Figure 30-8-3. The reverse indicator method is normally used. First, the indicator is mounted on the power hub such that its axis of revolution is the same as the power hub. Rotation of the dial indicator indicates deviations in the surface of revolution of the load hub. Then the dial indicator is centered on the load hub and readings are taken on the power hub.

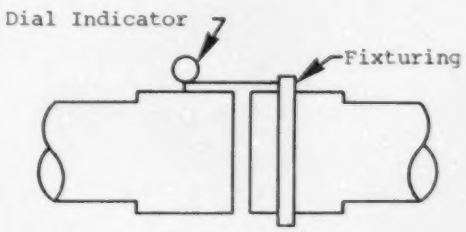


Figure 30-8-3. Alignment Inspection With Dial Indicator

Visual inspections are performed to verify completeness of installation. These inspections may also include witnessing of torquing of threaded fasteners. Typically, visual inspection verifies that the following have been installed or connected as specified by the job package:

- power cables between motors and switch gear
- power cables between generator and output breaker
- external excitation cables
- instrumentation lines
- control circuitry, including relays, switches, stops
- lubrication lines
- cooling lines
- steam lines to turbines
- fuel oil lines to diesel engines

Upon completion of installation, freedom of movement of the rotors of rotating equipment is checked. This check is made by first visually inspecting the equipment for

freedom from foreign objects. Then, the rotor is manually turned and observed for binding or rubbing. Upon satisfactory completion of this check, the equipment is released for preoperational testing.

LUBRICATION

Purpose and Theory

The purpose of a lubrication systems as applied to rotating equipment is to reduce the friction between moving parts by replacing solid friction with fluid friction. This reduction in friction produces two desired effects: (1) the quantity of energy required to perform the mechanical action (rotation) is reduced and (2) the amount of energy that is dissipated as heat is reduced.

Fluid lubrication provides physical separation of surfaces such that metal-to-metal contact is avoided. This is possible due to two important components of fluid friction: (1) cohesion between particles of the lubricating fluid and (2) adhesion of the fluid particles to the object which is tending to move the fluid. As long as the fluid flow remains intact, the only friction present is fluid friction, which is desired.

The Langmuir Theory of lubrication explains that, there are three or more layers of films of lubricant existing between two lubricated bearing surfaces. This is illustrated in Figure 30-8-4. As illustrated, the two outer most layers (1 and 5) are boundary films with one adherent to the stationary member and one adherent to the moving member. The two boundary layers are separated by one or more fluid films. When the rotating journal begins its motion, the position of the journal relative to the bearing lining is such that a wedge of lubricants is formed. The oil layers between the boundary layers continuously provides through cohesion, a physical separation between the two metal surfaces thus providing the desired fluid friction.

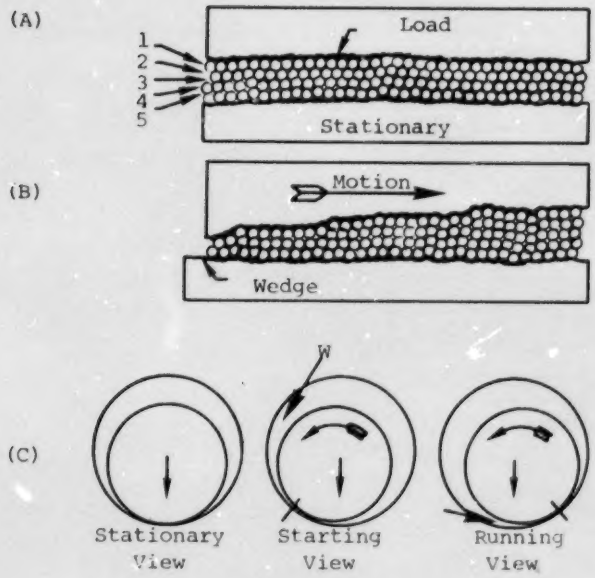


Figure 30-8-4. Oil film lubrication, (A) Stationary position, showing several oil films; (B) surface set in motion, showing principle of oil wedge; (C) principle of (A) and (B) shown in a journal bearing.

Characteristics of Lubricants

There are two basic types of lubricants used in nuclear power plants; these are oils and greases. Oils are typically used by turbines, internal combustion engines, combustion turbines, large motors and reduction gears. Grease is employed where the retention of lube oil at the bearing surface may be difficult, i.e. valve reach rods/extensions, horizontal small motors, or gear chains.

The following attributes of oils are of concern in selecting the specific oil to be used. Component and system design specifications state specific values for these attributes. Installation inspection verifies that oils having specified attributes are used.

- viscosity - its tendency to resist flow or change of

shape

- pour point - lowest temperature at which the oil will barely flow from a container
- flash point - point corresponding to the temperature at which enough vapor given off to flash when a flame or spark is present
- fire point - point corresponding to the temperature at which the oil will continue to burn when ignited
- auto-ignition point - corresponding temperature at which the flamable vapors given off from the oil ignite without the application of a spark or flame
- neutralization number - the measure of the acid content in terms of milligrams of potassium hydroxide (KOH) required to neutralize one gram of the oil
- demulsibility - the ability to separate cleanly from any water present
- precipitation number - measure of the amount of solids or asphalts or carbon residue contained in the oil.

Greases are classified by application within the plant. These classifications are:

- Group I - General purpose, operating temperature range - 40 to 250°F
- Group II - High temperature, operating temperature range - 0 to 300°F
- Group III - Medium temperature, operating temperature range - 32 to 300°F
- Group IV - low temperature, operating temperature range - 67 to 225°F
- Group V - extreme high temperature, short period operating temperature up to 450°F

Oil Lubrication Systems

The three basic types of oil lubrication systems used within nuclear power plants are (1) Force Feed,

(2) Gravity feed and (3) self oiling system. The first, force feed, is subdivided into attached types as in the case of the oil system of a diesel engine and the external type as in the case of a large turbine generator complex.

The attached force feed oil lubrication system, as represented by the diesel oil system illustrated in Figure 30-8-5, depends upon the diesel engine as the prime mover for the attached oil circulating pump. This pump is coupled to the crankshaft through a series of gears and provides oil flow only when the engine is operating. In addition to strainer and filters, the lubrication system has an oil cooler and relief protection. The typical loads or items to be lubricated by this system are:

- main crankshaft bearing
- main thrust bearing
- running gear
- cam shaft bearings
- turbocharger bearing
- front gear train.

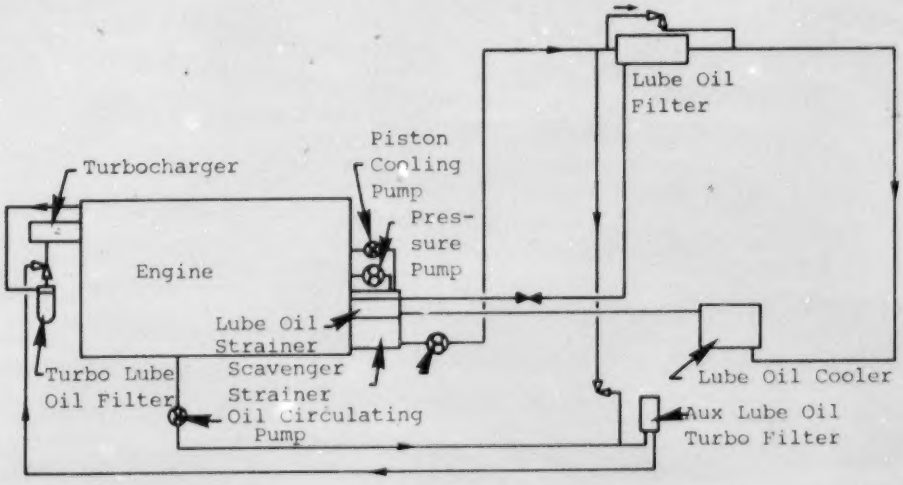


Figure 30-8-5. Attached Lube Oil System

The external forced feed oil lubrication system differs from the attached system in that the components being lubricated depend upon an externally powered force feed oil system which typically is called an auxiliary system. The external oil lubrication system is illustrated in Figure 30-8-6.

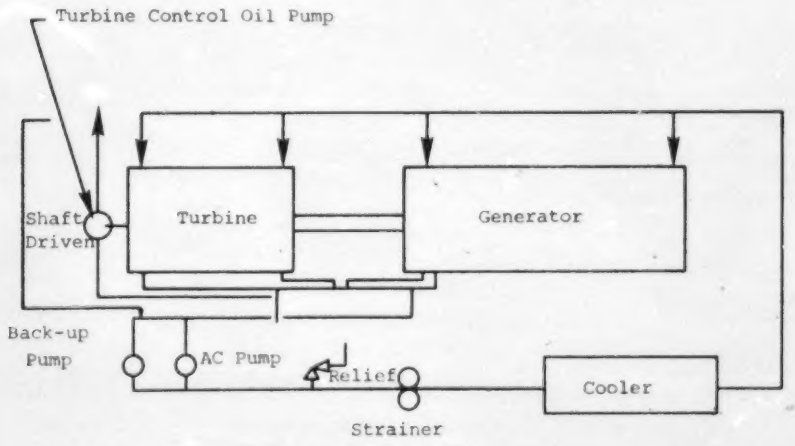


Figure 30-8-6. External Lube Oil System

As illustrated by figure 30-8-6, an AC motor driven lube oil pump supplies the oil to the bearings of the turbine and the generator. This AC pump has an emergency back-up pump which is powered from an independent power source thus providing protection from a loss of normal power. A shaft driven oil pump is used in this system, but not for lubrication purposes. Instead, it supplies the control oil for the turbine control system. Like the previous system there are reliefs, strainers and coolers.

Gravity feed applications as illustrated by figure 30-8-7, are more simple and are basically either, drip feed,

vibrating pin or wick feed. In each of these cases the lubrication is localized such that each device usually services only one component, e.g., one bearing. These devices are under a scheduled service routine to ensure that the reservoir has sufficient oil for the intended lubrication period. These units find limited application in power plants.

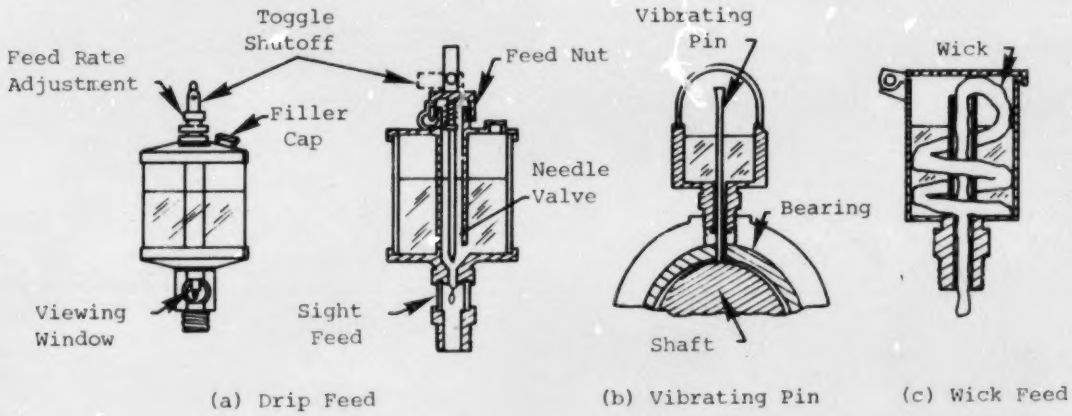


Figure 30-8-7. Gravity Feed Lubrication Units

"Self-oiling" lubrication systems are illustrated in Figure 30-8-8.

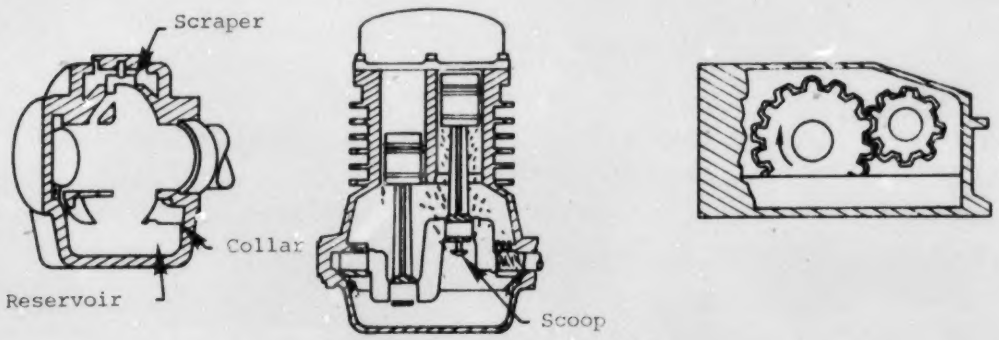


Figure 30-8-8. Self Oiling Lubrication Systems

In each of the examples shown in Figure 30-8-8, a transfer device (collar, scoop or gear teeth) is used to transfer the oil from the sump to the area where fluid friction is desired. This method is very simple as in the case of the gravity feed system but enjoys wider application in the power plant due to its greater reliability. While the sumps provide a return for the excess oil, there is still a need to provide scheduled surveillance to ensure quantity and quality of the oil.

Grease Lubrication

As described earlier, grease lubrication is used in locations where the retention of lube oil at the bearing surface is difficult. The two basic types of grease application widely used in the power plant are grease cups and pressure fittings.

The grease cup is used to force grease into a grease cavity be means of a screw arrangement. The cavity is directly open to the cup and usually minimum force is required to introduce new grease to the component. Figure 30-8-9 illustrates a grease cup. A drawback associated with this form of lubrication is the tendency to overgrease. Grease cups may be used on small motors, valve stems and sometimes on pump packing glands.

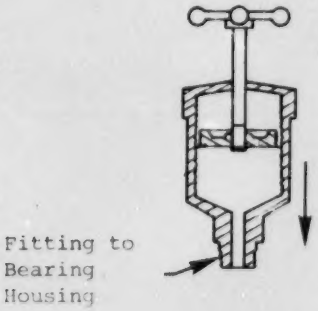


Figure 30-8-9. Grease Cup

Pressure fittings, often termed "ZIRK", are used primarily for small motors, valve stems, and pump packing glands. As illustrated in Figure 30-8-10, grease is forced by a grease gun through the fitting ball valve to the bearing. The ball valve is spring loaded to prevent reverse flow. Usually the old grease is forced out of the bearing as the new grease is forced in. The major advantage of the grease fitting over the grease cup is the ability of the grease gun to apply fresh grease which has not been subjected to environment prior to use.

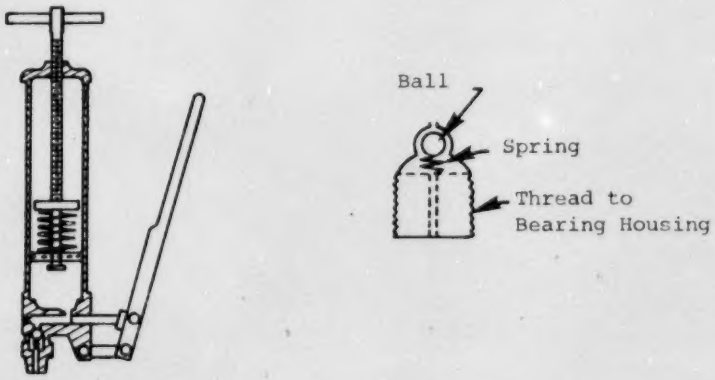


Figure 30-8-10. Grease Gun and Fitting

Functional Testing of Lubrication Systems

Lubrication systems are initially tested by the installation contractor prior to turn over of the component/system to the owner/operator. At this time a functional test of the lubrication system is conducted under no load conditions if at all possible. In the case of attached force feed systems (e.g. diesel) a "no load" test is impossible. In cases like this, the initial test is under as minimal a load as possible. However for the external forced feed oil system, a no load test is possible.

Regardless of the load, the initial turnover tests verify that the lubricating system functions in terms of oil flow and pressure.

Turnover tests without applying a load condition actually indicate satisfactory operation "so far". This is acceptable at this point because the primary concern is with individual lubrication flows to the respective components. Once this basic fact is established, the owner/operator performs more detailed load acceptance tests. Additional items which are checked during turnover tests are:

- standby features
- pump vibration
- strainer cleanliness
- foaming
- tightness of joints
- level alarms
- sight flows
- temperature detector operability
- relief valve operation
- pressure regulating valve operability.

Load acceptance tests are typically accomplished in conjunction with component load testing during cold and hot functional testing. Such load tests are described later in this module. During these tests, additional characteristics checked with respect to lubrication are:

- lube oil temperature rise across bearing
- return oil flows
- lube oil cooler operation
- oil pressure regulator operation under elevated temperatures
- bearing temperature.

While the preceding tests directly apply to "lubrication system", the same principles are applicable to the gravity feed arrangements and the grease cups. Checks on these systems include:

- oil level in reservoirs.
- smooth and quiet operation of the equipment.
- cool bearing operation (e.g., not hot to the touch)
- oil visible in viewing windows.

In summary, lubrication is essential to the operation of rotating equipment and regardless of the size of the component, the same questions need to be answered by the inspector:

- Does the unit have lubrication?
- Is it the correct type as called for by design?
- Does the "lubrication system" lubricate and provide fluid friction for the rotating components as evidenced by temperatures, vibration, and oil flows and pressures?

ELECTRICAL TESTS

Types of Tests

The extent of testing of rotating equipment is specified by engineering based on regulatory requirements and importance of the equipment to the safe operation of the power plants. Tests are time-sequenced to permit necessary interfacing with other plant systems. Typical tests in their order of performance are as follows:

- continuity tests
- insulation resistance test
- high potential dielectric test
- starting and run current tests
- vibration tests
- generator loading tests
- automatic features actuation tests.

Continuity Tests

Continuity tests verify that power control and instrumentation conductors are connected to correct terminals and have electrical continuity. These tests check continuity of conductors from the equipment to the first breaker, switch, or relay in the cable run. The remainder of power distribution and circuitry are tested separately. Figure 30-8-11 illustrates the continuity test.

Referring to Figure 30-8-11, the phase C conductor is tested individually by lifting the connection at one end. This removes circuit paths through the motor which could disguise improper wiring. If phase C at the motor is connected to phase C at the switch gear, the voltmeter reads applied voltage provided no opens or shorts exist on conductor C. Otherwise, the voltmeter reads zero. Phase C is then reconnected, and the other phases are individually tested in like manner.

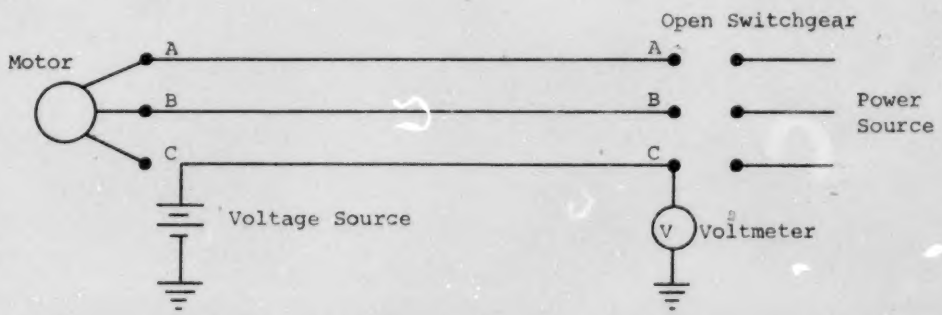


Figure 30-8-11. Continuity Testing

Insulation Resistance

Insulation resistance is the term used to describe the quotient of applied direct electrical potential divided by current caused by that potential at some given time after application of the potential. The potential is applied between the conductor and ground. Therefore, the current

caused by the potential must flow through the insulation which surrounds the conductor. The relationship is expressed by a variation of Ohm's law:

$$R = \frac{E}{I} \qquad \text{Equation 30-8-1}$$

where:

R = insulation resistance

E = potential applied

I = current measured

The fundamental concept of insulation resistance is illustrated in Figure 30-8-12. As illustrated, insulation resistance is inversely proportional to the cummulative currents in all possible leakage paths.

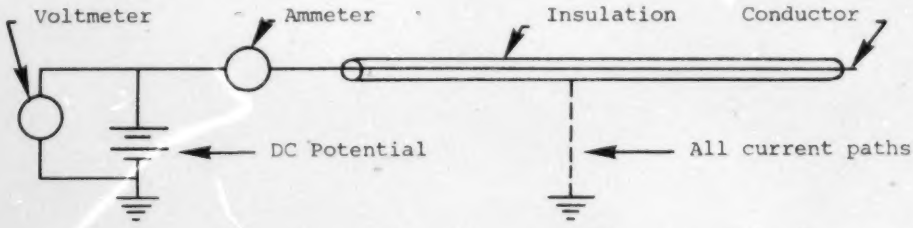


Figure 30-8-12. Insulation Resistance

Referring to Figure 30-8-12, the current at the instant of application of the potential is comprized of three components. First, capacitance charging current is initially of relatively high value. This current decays rapidly and is of short duration. Due to the rapid decay, capacitance charging current does not affect the measurement of insulation resistance. Second, absorption current is initially of a comparatively high value and slowly decays to essentially zero. This current is within the volume of insulation and affects measurement of insulation resistance

for several minutes. Third, conduction current is essentially constant if all other conditions are constant. Conduction current is the surface leakage current to ground.

The insulation resistance of windings withing rotating equipment is a function of the type and assembly of insulating material. In general, insulation resistance varies directly with thickness of insulation and inversely with conductor surface area. Potential paths for conduction current includes from phase to phase and from phase to ground. Insulation resistance is affected by (1) surface condition, (2) moisture, (3) temperature, (4) magnitude of test potential, and (6) residual charge in the winding.

Foreign matter, such as carbon dust, or insulation surfaces tend to lower insulation resistance. As moisture content of such foreign matter increases, the insulation resistance generally decreases substantially. Cleaning and drying insulation surfaces normally brings insulation resistance up to its normal value.

Regardless of cleanliness of insulation surfaces, moisture films on insulation surfaces tends to lower insulation resistance. Many insulation materials absorb moisture to some extent and are very susceptible to decreases in insulation resistance with increasing moisture content. This adverse effect can be avoided by keeping the windings above dew point temperature when the equipment is idle.

Insulation resistance of most materials varies inversely with temperature. Generally, measured insulation resistance doubles for each $10^{\circ}C$ reduction in temperature. Measured insulation resistance is corrected to the established standard temperature of $40^{\circ}C$ by the formula:

$$R_c = K_t \times R_t \qquad \text{Formula 30-8-2}$$

where:

R_c = insulation resistance corrected to 40°C in megohms

K_t = insulation resistance temperature coefficient at temperature t

R_t = measured insulation resistance at temperature t in megohms.

The insulation resistance temperature coefficient may be determined by measuring insulation resistance at several temperatures, all above the dew point, and plotting the results. Using the plot, the temperature coefficient at any temperature can be calculated by solving Formula 30-8-2 for K_t. An approximate value of K_t is given in Figure 30-8-13 which is based on a doubling of insulation resistance for each 10°C reduction in temperature.

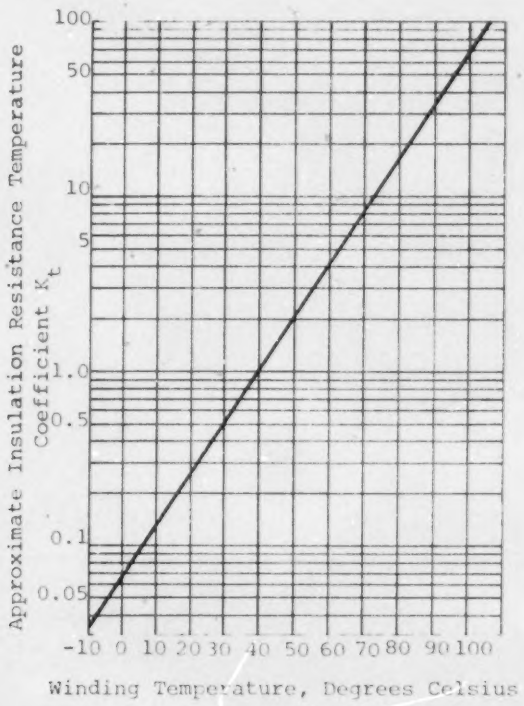


Figure 30-8-13. Approximate Insulation Resistance Temperature Coefficient with Temperature

The test potential used for measuring insulation resistance must be equal to or less than the peak voltage rating for the winding in its basic condition. Variation of test potential below voltage rating yields essentially constant measurements of insulation resistance provided the insulation is clean and dry. If resistance decreases substantially with increasing test potential below voltage rating, the insulation probably contains imperfections or cracks aggravated by foreign matter or moisture. Test potentials above voltage rating overstresses the insulation. Excessive test potentials yield a decreasing resistance reading as test potential increases.

As the duration of application of test potential increases, the measured value of insulation resistance increases up to a fairly stable value. This effect is primarily caused by absorption current. The increase in measured resistance initially increases rapidly from the time of application of test potential but then gradually approaches a stable value. A fairly steady value is typically reached in ten to fifteen minutes.

Foreign matter and moisture not only lowers the measured value of insulation resistance but also lowers the rate of rise of resistance with duration of test potential. Therefore, the rate of rise of insulation resistance with duration of test potential is useful in appraising the cleanliness and dryness of windings. To provide such appraisal, the polarization index may be used for acceptance of insulation resistance. Polarization index is indicative of the rate of rise in insulation resistance with duration of test potential and is calculated by:

$$PI = \frac{R_{10}}{R_1}$$ Formula 30-8-3

where:

PI = polarization index

R_{10} = insulation resistance at 10 minutes after application of test potential

R_1 = insulation resistance at 1 minute after application of test potential

Residual charge in the windings causes erroneous readings of insulation resistance. Prior to connecting the measurement equipment, residual charge is removed by grounding the winding to be measured. Also, after measuring insulation resistance, the winding is again grounded to remove residual charge caused by application of the test potential. Such grounding dissapates capacitive and absorption current. Grounding time is four times the charge time.

Insulation Resistance Tests

All measuring equipment for insulation resistance work on the concept illustrated in Figure 30-8-12. Variables among types of equipment include test potential and power source. Basically measuring equipment have test potentials in the range of 500V to 5000V and are available in the following types:

- direct indicating ohmmeter with hand or power driven generator.
- direct indicating ohmmeter with self contained battery
- direct indicating ohmmeter with self contained rectifier and external AC power source.
- resistance bridge with self contained galvanometer and batteries.

In addition to equipment designed for measuring insulation resistance, the test set-up illustrated in Figure 30-8-12 can be used. That is, an appropriate power source, a voltmeter, and a microammeter can be individually connected as illustrated. In such cases, insulation resistance is calculated by Formula 30-8-1.

Regardless of the instrument used, certain prerequisites are observed prior to measuring insulation resistance. These prerequisites are verification that:

- winding temperature is above dew point
- residual charge is dissapated
- test potential is equal to or less than peak voltage rating of the winding.

Insulation resistance tests of windings of three phase rotating equipment are made with the neutral end of each phase disconnected when possible. In this manner, phase-to-phase insulation resistance as well as phase-to-ground insulation resistance is tested. In addition, external circuits which affect winding insulation resistance measurements are disconnected when possible. This includes disconnecting power leads, brush rigging, switches, capacitors, and lightning arrestors.

Acceptance criteria for insulation resistance is specified by engineering as either minimum resistance or minimum polarization index. Therefore, the insulation resistance test verifies the quality of insulation in terms of actual resistance or polarization index.

Minimum resistance applies to the measured value at one minute after application of test potential and corrected to 40°C. Minimum polarization index applies to the ratio of the ten minute reading to the one minute reading. Resistance readings are always corrected to 40°C. Temperature effect on polarization index is small if winding temperature at the ten minute reading is essentially equal to temperature

at the one minute reading. However, at high temperatures, the temperature characteristics of the insulation may yield an abnormally low polarization index. Another test at a temperature below 40°C should be made in such cases to better determine the real insulation resistance.

Acceptance criteria in terms of polarization ratio typically requires a minimum ratio of 1.5 or 2.0 depending upon class of insulation. Values as high as 7 may be obtained in measurements. Minimum insulation resistance at the one minute reading is typically based on effective voltage rating of the rotating equipment. The relationship is expressed by:

$$R_m = kv + 1 \qquad \text{Formula 30-8-4}$$

where:

R_m = minimum insulation resistance at 40°C of entire machine winding in megohms

kv - rated machine terminal to terminal potential in rms kilovolts

Example:

Problem: Does the insulation resistance reading of 25 megohms measured at 22°C indicate compliance with the specified minimum insulation resistance of 10 megohms?

Given: R_t = 25 megohms, t = 22°C, R_m = 10 megohms

Solution: Determine k_t from Figure 30-8-13.

k_t = 0.3

Using Formula 30-8-2, calculate R_c

$R_c = K_t \times R_t$

$= 0.3 \times 25$

$= 7.5$ megohms

Because 7.5 < 10, the insulation resistance fails to meet acceptance criteria.

Example:

Problem: Is winding insulation acceptable if a minimum of 2.0 polarization index is required, the one minute insulation resistance measurement at 60°C is 100 megohms, and the ten minute measurement at 55°C is 380 megohms.

Given: R_{t1} = 100 megohms, t_1 = 60°C, R_{t10} = 380 megohms, t_{10} = 55°C, PI_m = 2.0.

Solution: Obtain temperature coefficients from Figure 30-8-13 and correct the one minute and ten minute readings to 40°C

R_{c1} = 4.1 x 100

= 410 megohms

R_{c10} = 3 x 380

= 1140 megohms

Calculate polarization index

$$PI = \frac{1140}{380}$$

= 3

Because 3 > 2, the windings are acceptable

High Potential Dielectric Tests

High potential dielectric tests determine the maximum potential which insulation can withstand without failure. This test is applied only to large AC machines rated at 10,000 kVA or greater and 6000V or higher. The test may be performed by the manufacturer or by the installer or both. Maximum test voltage is as much as 2.5 times the rated voltage of the machine but lower than anticipated breakdown voltage of the insulation.

Insulation is verified to be in good condition prior to performing a high potential test. Typical prerequisites for the test include verification that (1) insulation resistance is greater than the specified minimum, (2) polarization index is greater than the specified minimum, and (3)

winding temperature is 40°C or greater. In addition, all auxiliary equipment is disconnected and each phase is independently tested insofar as possible.

Special test equipment is needed for high potential dielectric tests. The high DC voltage is typically provided by a variable autotransformer and rectifier. The line voltage and frequency to the primary of the autotransformer are regulated to avoid variations in test measurements due to line variations. Other loads on the line supply are not changed for the duration of the test. The autotransformer is adjustable in small continuous increments. A kilovoltmeter with several ranges is included. Microammeters have several ranges and electrostatic shielding. Large leads, substantial ground straps and elimination of sharp corners in all connections reduce corona effects. The basic test arrangement is illustrated in Figure 30-8-14.

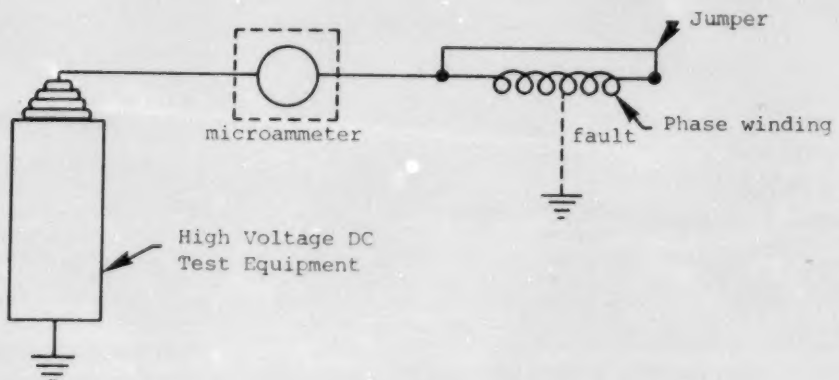


Figure 30-8-14. High Voltage Test Arrangement

High potential dielectric tests may be performed as proof tests or controlled overvoltage tests. The proof test determines if insulation withstands the applied test

voltage. The controlled overvoltage test predicts breakdown voltage and provides information for comparison among phases or subsequent tests.

Proof tests are performed by gradually increasing test voltage and observing the current measurement. If current exceeds the specified maximum at any time, test voltage is reduced and the test is terminated until cause of the excess current is determined and corrected. If current does not exceed limits, test voltage is gradually increased to maximum test voltage and held for one minute. If no evidence of distress or failure is observed at the end of one minute, at maximum test voltage, the machine is considered satisfactory and test voltage is slowly reduced. At the conclusion of the test, the winding is grounded for a time at least equal to four times the duration of the test to dissipate residual charge.

Controlled overvoltage tests are performed by timed increments and increasing test voltage while plotting measured current against applied voltage. Initially, approximately one-third of maximum test voltage is applied and held for ten minutes to permit calculation of polarization index. If the polarization index is satisfactory, test voltage is increased at one minute intervals in steps of 3% or less of maximum test voltage. The voltage adjustment is made within the first 10 seconds of the one minute interval and not adjusted again until the next interval. The current is measured at the end of each one minute interval and immediately plotted. The series of voltage increases and current measurements are continued until there is indication of pending failure or maximum test voltage is reached, whichever first occurs.

Indication of pending failure of the insulation is provided whenever there is a marked change in the slope of the plot as illustrated in Figure 30-8-15. Such indication normally occurs at a test voltage at least 5% below estimated breakdown voltage. The breakdown voltage is estimated by extrapolation to the point where the curve is vertical. Test voltage is increased one additional increment

if conservatism permits. If pending failure is still indicated by extrapolation of the plot, the test is terminated.

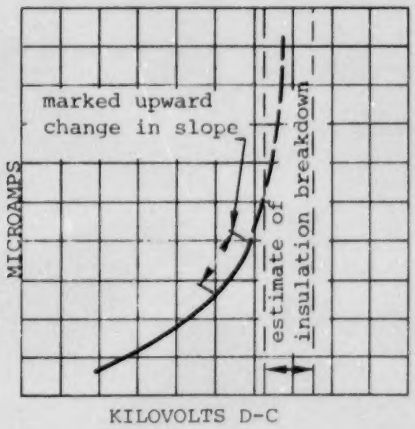


Figure 30-8-15. High Potential Dielectric Test Results

The high potential dielectric test is terminated by slowly reducing test voltage. This avoids rapid field changes which might induce failure. After reducing test voltage, the winding is grounded by a grounding rod with a resistor and then grounded with a grounding rod without a resistor. Then a grounding strap is attached and left in place for about one hour to ensure dissipation of residual charge.

High potential dielectric tests are used to predict when maintenance is necessary. The initial test of new equipment provides data against which subsequent tests are compared. When tests indicate breakdown voltages lower than anticipated, some deterioration in insulation is suspected and maintenance is scheduled.

Starting and Run Current Tests

Starting and run current tests verify acceptable motor

performance under load. (It is noted that generator tests are described later in this module.) These tests are conducted as preoperational or cold functional tests and require that load systems and motor lubrication and cooling systems be functional.

Current is typically measured with portable tong meters although chart recorders and permanently installed ammeters may be used. Tong meters operate on a principle illustrated in Figure 30-8-16. The magnetic field around a conductor induces current flow in the magnetic tong. The magnetic field of this secondary current flow is sensed and displayed on a meter. Tong meters are available as ammeters, voltmeters, watt-meters, volt-amp meters, and power factor meters.

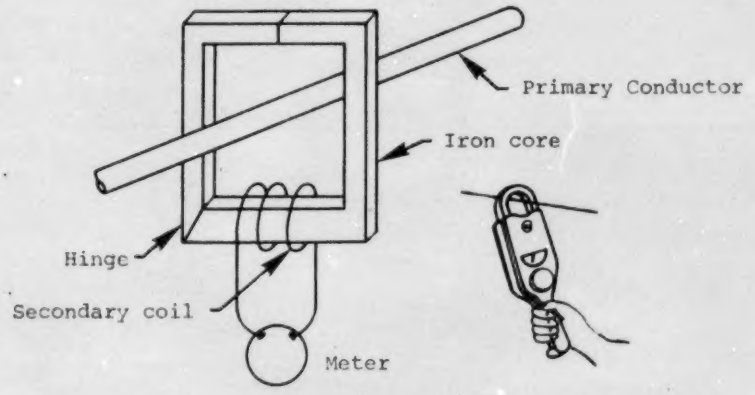


Figure 30-8-16. Tong Meter Operation

Tong meters with special stops are used for measuring starting current. In these, the meter indicator is locked at its maximum reading and does not return to zero until the lock is released. In this manner, peak current which occurs at initial start of the motor is captured and hence, readable.

Starting and run current tests are performed with the

motor subjected to the loading conditions which occur in plant operation. If the motor normally starts with load, the test is performed with load. If the motor normally has load applied after being started, the test duplicates these conditions. Starting current is measured under normal starting conditions and run current is measured with the motor fully loaded. The measured values are compared with specified limits to determine acceptance. Limits are specified by system design specification and nameplate.

During run current tests, motor and bearing temperatures are also checked for compliance with limits. This confirms adequate cooling and lubrication of the motor and its bearings.

Vibration Tests

Vibration tests verify that rotating equipment are sufficiently rigid, aligned, and balanced to avoid excessive vibration during operation. These tests are performed for turbines, motors, and generators. The equipment is typically tested in the no-load condition and then tested at various loads up to full load. Vibration may be caused by misalignment, loose mounts, worn bearings, unbalanced rotor, bent or cracked shaft, or excessively pulsating loads.

Basic limits on vibration are typically specified in "mils" where a mil equals 0.001 inch. Several direct reading vibration detectors are available for measuring vibration in mils. One type uses a dial indicator with a plunger through a spring within a weighted case. The inertia of the weighted case causes it to remain relatively stationary when the instrument is placed in contact with a vibrating surface. The vibrations are transmitted by the plunger to the dial indicator such that the indicator reading oscillates between points on the dial. The difference between the maximum points of oscillation equals

the peak-to-peak vibration in mils. Another type of instrument has a stylus connected to a mirror such that the tilt of the mirror oscillates proportional to vibration. A point light source directed at the mirror reflects to a frosted scale and appears as a white line. The length of the line indicates peak-to-peak vibration in mils.

Basic vibration tests use portable vibration detectors in contact with bearing and coupling housings to measure vibration. Measurements are typically made at no-load, partial load, and full load conditions. Results are compared directly with specified limits for acceptance.

Continuous vibration monitoring of generator sets is increasingly being used. Continuous monitoring systems use piezoelectric crystals mounted on key surfaces and attendant electronic circuitry for measuring output of the crystals. These systems provide for several measurements. Measurement of amplitude of all frequencies of vibration provides an equivalent reading as the vibration detectors previously described. Total amplitude is typically used to initiate an alarm and equipment shutdown at consecutively higher levels of vibration. This protects the equipment from catastrophic failures when more minor problems are causing an increasing vibration. In addition, many of these systems have electronic circuits which measure frequency and phase components of vibration. This permits vibration analysis vice monitoring. Vibration analysis is used to detect deteriorating conditions and to pinpoint the parts causing the vibration. In this manner, maintenance is scheduled before failure occurs.

Generator Loading Tests

Generator loading tests verify the mechanical and electrical performance of generators under various load conditions. These tests are performed for motor-generators,

turbine-generators, and diesel-generators.

Stator winding temperature and bearing temperatures are the principal temperatures of concern for AC generators. Armature temperature is also of primary concern for DC generators. These temperatures are measured by permanently installed detectors or by measuring temperatures of the cooling medium. Thermocouples or resistance temperature detectors provide for temperature detection. Cooling mediums may be air, water, or hydrogen.

Tests are performed by sequential loading of the generator while normal cooling and lubrication methods are functioning. Temperatures are monitored to determine that anticipated cooling of both windings and bearings occurs. Loading continues until rated generator capacity is reached. Full load is continued for a specified "run" time to verify satisfactory cooling and lubricating at continuous duty at full load. Vibration tests may be conducted simultaneously.

At intervals of loading, the electrical performance of the generator is checked. These checks typically determine speed and voltage controls and may also, measure phase balance, and power factor. For AC and DC generators, output voltage is variable with speed and field current. Also output frequency of AC generators is variable with speed. In most applications speed is held constant at the correct rpm and field current is adjusted to maintain voltage. As loading increases, the power transmitted by the prime mover must increase in order to maintain constant speed. Automatic or semi-automatic controls are typically used to adjust power to the prime mover to maintain constant speed and to adjust generator field current to maintain output voltage. The control devices permit manual adjustments by operators as necessary. The proper functioning of the speed and voltage controls as well as the manual adjustments are checked during loading tests.

Automatic Features Actuation Tests

In the event of loss of reactor and off-site power, diesel-generators automatically start and supply emergency power to critical components which provide for safe reactor cooling. Automatic features actuation tests verify that the emergency diesel generators start and supply power to loads as designed whenever actuating conditions occur.

Actuating signals for emergency diesel-generators originate from certain plant parameters and power on essential electrical busses. Plant parameters are typically containment radiation, reactor coolant pressure, and containment pressure. Abnormal values for these parameters are indicative of some type of accident which may require emergency power. Loss of voltage on essential busses is definitely indicative of the need for emergency power. A simplified block diagram of actuating signals is given in Figure 30-8-17.

Referring to Figure 30-8-17, essential bus loads are normally supplied by the main turbine generator or off-site power. The diesel generator is shutdown and its output breaker is open. The plant parameters are normally within design limits and there is no signal from any of the bistables. It is noted that three or four redundant channels which are not shown in Figure 30-8-17 are used for measuring each plant parameter. In order to trigger the bistable, at least two channels for a given parameter must reach the trip point. This precludes actuation by a single, false signal.

High containment radiation, high containment pressure, or low reactor coolant pressure trips their bistable and sends a signal which starts the diesel. This prepares the diesel for supplying power if normal power to the essential bus is also lost. Whenever normal power to the essential bus is lost, the voltage sensor initiates a signal which

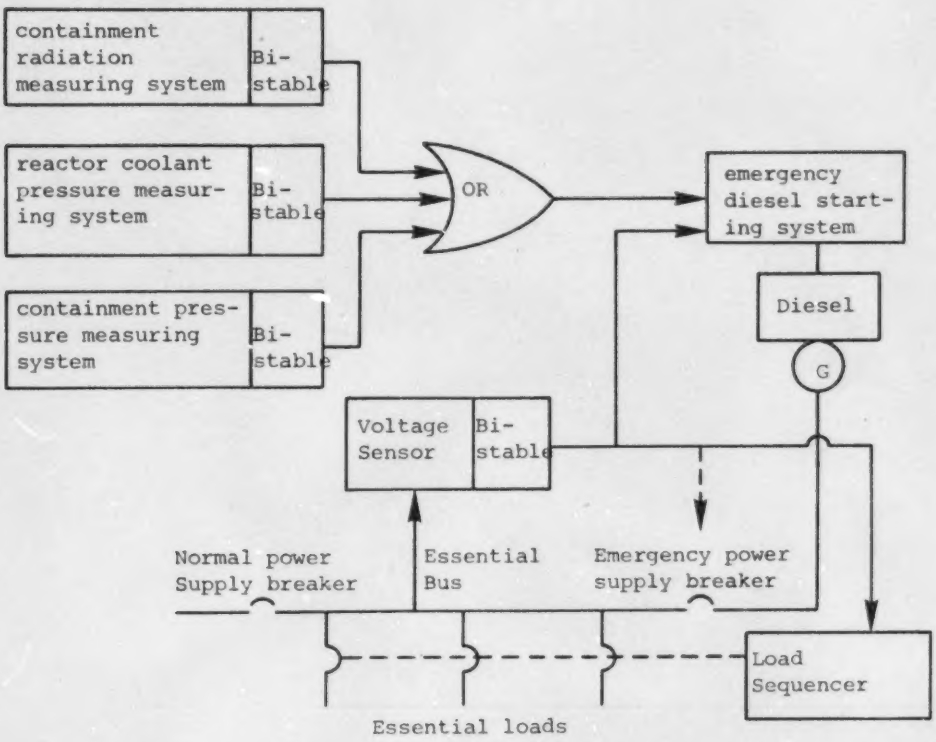


Figure 30-8-17. Simplified Block Diagram of Safety Features Actuation of Emergency Diesel Generator

starts the diesel and activates a load sequence. Simultaneously, the normal supply breaker trips open on undervoltage and the voltage sensor closes the diesel-generator output breaker. Therefore, as the diesel is coming up to speed under loss of normal power conditions, its output breaker is closed. Because essential loads may initially overload the diesel-generator, breakers to essential loads are also equipped with undervoltage trips and these breakers open upon loss of normal power. The load sequencer recloses breakers to essential loads at timed intervals of about five

seconds each. This permits the diesel-generator to reach operating speed prior to loading and it staggers the starting currents of essential loads. In this manner, power is quickly and safely restored to essential loads such as core spray pumps, safety injection pumps, containment spray pumps, power operated valves in these systems, and reactor instrumentation and control systems.

Tests of safety features actuation of the emergency diesel generator are performed as two separate tests. One simulates plant parameters, confirms bistable trips at specified set points, and verifies diesel starting. The other test opens the normal supply breaker and verifies diesel starting and load sequencing. Test prerequisites establish system lineup of the affected systems such that emergency sprays and injections do not actually occur as a result of the test.

EXERCISES

This check list summarizes the major points of this module. Put a check by each point as you recall it.

____ Preinstallation inspections verify readiness for installation in terms of materials, procedures, and drawings.

____ Preinstallation inspections are primarily visual inspections which verify (1) component identification, (2) availability of processes and procedures, (3) physical condition of the component, and (4) physical condition of the installation area.

____ Installation inspections verify completion of installation work in compliance with the procedures and drawings which comprize the installation job package.

____ Installation inspections are primarily dimensional inspections of leveling and alignment, visual inspections of completeness of installations, and verification of freedom of rotation by manually rotating the equipment.

____ Alignment inspection methods include the straight edge and dial indicator methods.

____ Lubrication according to the Langmuir theory provides fluid friction by the adhesion and cohesion properties of oils which result in layers of oil forming a separating wedge between rotating and stationary member.

____ Important properties of oils include viscosity, flash point, fire point, auto-ignition point, neutralization number, demulsibility, and precipitation number.

____ Types of oil lubricating systems include force feed, gravity feed, and self oiling.

____ Forced feed oil systems include those with oil pumps attached to and driven by the equipment being lubricated and those with separate oil pumps powered by external sources.

____ Gravity feed oil lubrication systems use an oil reservoir which provides oil feed by gravitational flow.

____ Self oiling lubrication systems use an oil sump from which tranfer devices attached to the equipment being lubricated lift oil to the areas to be lubricated.

____ Grease lubrication systems include grease cup and grease fitting. Grease cups contain a reserve of grease which is forced into the part by a threaded plunger or piston. Grease fittings permit application of grease by grease gun.

____ The installation contractor performs turnover tests of oil lubrication systems which verify operability of the system under no load conditions.

____ The owner performs load testing of rotating equipment which also includes verification of functions of the lubricating system under load conditions.

____ Continuity tests verify that conductors are connected to correct terminals and have continuity.

____ Insulation resistance is affected by surface condition, moisture, temperature, magnitude of test potential, duration of application of test potential, and residual charge.

____ Insulation resistance tests either measure insulation resistance at one minute after application of test potential or measure polarization index.

____ Insulation resistance measurements are always corrected to 40°C.

____ High potential dielectric tests determine maximum potential which insulation can withstand without failure. This test may be conducted as a proof test or as a controlled overvoltage test.

____ Starting and run current tests verify acceptable motor performance under load.

____ Vibration tests verify that rotating equipment are sufficiently rigid, aligned, and balanced to avoid excess vibration.

____ Generator loading tests verify the mechanical and electrical performance of generators under various load conditions.

____ Automatic features actuation tests of diesel generators verify diesel starting and generator loading whenever actuating conditions occur.

MATERIALS

The following materials are required to support this module:

1. megohmmeter
2. motors suitable for inspection.

PROCEDURES

The following activities reinforce the information presented in this module.

1. Measure insulation resistance of a motor:
   a. Select a motor from available resources such as portable fans, vacuum cleaners, etc.
   b. Obtain a megohmmeter from the instructor. A hand-cranked 250V/500V megger or a megohm bridge will suffice.
   c. Connect a shorting wire across each power lead and to the case of the motor for a four minute interval and then remove the shorting wire.
   d. Determine maximum test voltage from nameplate data (Note: If name plate data does not identify maximum rated voltage, use 250V for 115V motors and 500V for 220V motors.)
   e. Ensure megohmmeter output voltage is equal to or less than maximum test voltage. (Note: handpowered meggers typically have a selector switch or different output terminals for 250V and 500V selection.)
   f. Connect megohmmeter positive lead to one power conductor and negative lead to the case of the motor.

Ensure the lead connected to the case makes metal-to metal contact without interference from paint or other foreign matter.

g. Measure and record insulation resistance.

h. Sequentially connect megohmmeter positive lead to each additional power conductor and measure and record insulation resistance.

i. Determine acceptance of measurements using Formula 30-8-4.

2. Calculate insulation resistance and polarization index from the following readings of a high potential controlled overvoltage test performed at 40°C. Plot the readings and determine the step which indicates impending breakdown. Determine breakdown voltage. Use Data Table 30-8-1 for plotting and recording.

Test Voltage (kV)	Current (mA)	Time From Start(min)
20	200	1
20	80	10
21.8	81	11
23.6	82.5	12
25.4	84.5	13
27.2	87	14
29	90	15
30.8	93.5	16
32.6	97.5	17
34.4	102	18
36.2	107	19
38	112.5	20
39.5	119	21
41.6	130	22
43.4	165	23

DATA TABLE

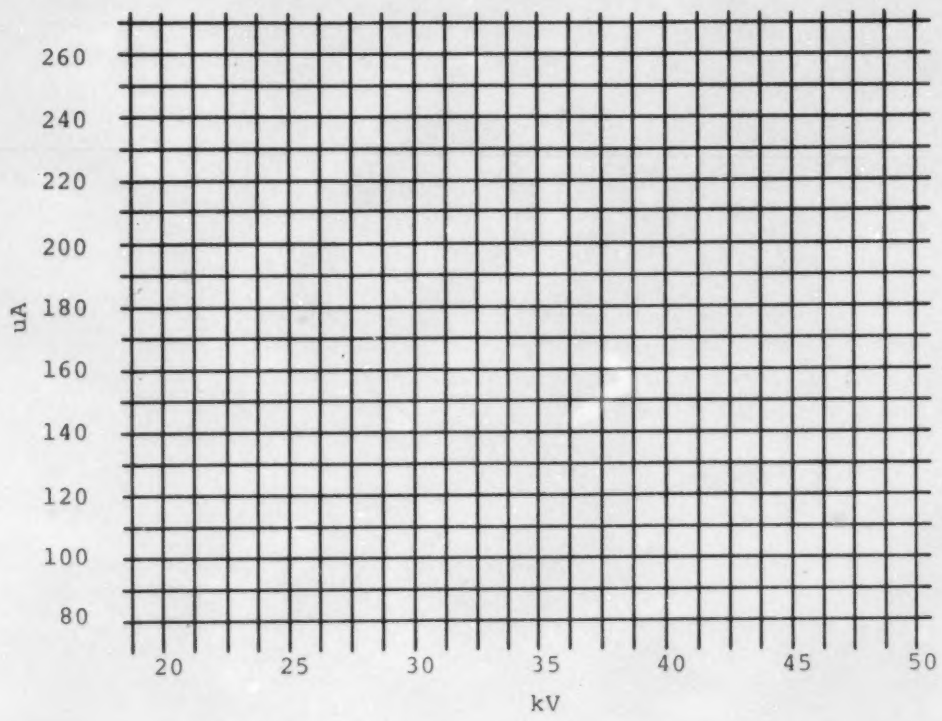
Data Table 30-8-1

Insulation Resistance at 1 minute:_____

Insulation Resistance at 10 minutes:_____

Polarization Index:_____

Estimated Breakdown Voltage:_____



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TEST

1. State the purpose of preinstallation inspections.

2. Briefly describe typical preinstallation inspections of rotating equipment.

3. State the purpose of installation inspections.

4. Briefly describe typical installation inspections of rotating equipment.

5. State why shaft alignment is important.

6. Name and briefly describe two methods of inspecting shaft alignment.

7. Briefly describe the Langmuir theory of lubrication.

8. Define the following attributes of lubricating oils:
   a. viscosity

   b. flash point

   c. fire point

   d. auto-ignition point.

9. Name three basic types of oil lubricating systems and briefly describe each.
   a.

   b.

   c.

10. Differentiate between the attached force feed and the external force feed oil lubrication systems.

11. Name two types of grease lubrication systems and briefly describe each.
   a.

   b.

12. State the purpose of "turnover" tests of oil lubricating systems and name four items checked by these tests.

13. Name three items checked during load testing to verify satisfactory performance of oil lubricating systems.

14. State the purpose of each test:
    a. continuity

    b. insulation resistance

    c. high potential dielectric

    d. starting and run current

    e. vibration

    f. generator loading tests

    g. automatic features actuation of emergency diesel generators

15. Describe the effects on insulation resistance measurements by capacitance current, absorption current, and conduction current.

16. Describe the effects on insulation resistance of:
    a. surface condition

    b. moisture

    c. temperature

    d. magnitude of test potential

    e. duration of application of test potential

    f. residual charge

17. Describe an insulation resistance test using the polarization index method.

18. Describe a high potential dielectric test using the controlled overvoltage test.

19. Describe a starting and run current test for an electrical motor.

20. Describe a vibration test using a portable vibration detector.

21. Describe a generator loading test.

22. Describe a basic automatic features actuation test for an emergency diesel-generator.